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Characteristics of Exposed Subsoil—At Exposure and 23 Years Later[1]

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ABSTRACT

The effects of topsoil removal on subsoil characteristics and productivity are usually studied at or soon after removal, with little attention to changes with time. The objective of this study was to evaluate the effects of 23 yr of exposure on the chemical and physical characteristics and productivity of various layers of Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls). An area on a 1% slope was leveled in 1960, giving plots with 0, 0.10, 0.20, 0.30, and 0.41 m of topsoil removal. The area was cropped to grain sorghum [*Sorghum bicolor* (L.) Moench] in fertility studies for 6 yr, fallowed for 2 yr, then planted to tall wheatgrass (*Agropyron elongatum*) and left undisturbed until 1983. The study was then reactivated with grain sorghum being grown without fertilizer 1 yr to determine fertilizer residual effects. In 1984 the previous N fertilizer treatments were reinstituted. During the 23 yr, organic matter (OM) and total N decreased in uncut surface soil but increased in exposed subsoil where initial levels were low. Extractable P levels and particle size distribution remained essentially unchanged. The proportion of large water-stable aggregates (4.0–12.7 mm) decreased, especially in the surface soil where OM decreased with time. Decreases in large aggregates were accompanied by increases in the 0.25- to 1.0-mm size range. Productivity of exposed subsoil layers increased over time. In relation to yields on similarly treated surface soil, yield reductions from soil removal (avg 0.10, 0.20, 0.30, and 0.41 m) in 1960 to 1962 and 1984 were as follows: unfertilized, 55 and 33%; P fertilized, 52 and 38%; N fertilized, 31 and 16%; N and P fertilized, 2 and 14%. Productivity increases were associated with increases in both N and P supplying capacity.

Additional index words: **Organic matter, Soil nitrogen, Extractable phosphorus, Soil aggregates, Soil productivity, Grain sorghum, *Sorghum bicolor* (L.) Moench.**

TOPSOIL may be lost by erosion or removed in water conservation practices such as bench leveling or other land shaping. The level of productivity to which subsoil can be raised, and treatments involved in reaching this level may determine the amount of topsoil loss or removal that is permissible or even if a given land shaping practice is feasible. The immediate loss of productivity and remedial treatments required for restoration are foremost at the time of topsoil loss or removal; however, time-affected changes in soil physical and chemical properties and in productivity may also be important criteria for making decisions regarding permissible topsoil loss or removal.

Several studies have been conducted in which variable thicknesses of soil have been removed to simulate loss by erosion or in land-forming procedures. Usually, immediate effects are reported in detail, but long-term effects are not measured or are given cursory treatment. Smith et al. (1967) compared grain sorghum [*Sorghum bicolor* (L.) Moench] yields on three plots of Austin clay (fine-silty, carbonatic, thermic Entic Haplustolls). One plot was desurfaced 0.38 m in 1931, another was desurfaced 0.38 m in 1961, and the third was allowed to erode normally. In the first 2 yr after topsoil removal, the plot desurfaced in 1961 yielded 66% less than the one that had been desurfaced in 1931. Average yield on the plot desurfaced in 1931 was 30% less than that on the plot with normal erosion. From the results of this work, Burnett et al. (1985) concluded that, with adequate fertilization, crop yields on severely eroded Austin clay can approach yields on soils with normal erosion. Black and Greb (1968) initiated a study on Weld silt loam (fine, montmorillonitic, mesic Aridic Paleustolls), shallow phase, in 1955 in which five increments of soil, from 0 to 0.38 m, were exposed. They established fertilizer treatments and grew crops. Soil physical and chemical characteristics and crop yields were measured. In sum-

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marizing the study, Greb and Smika (1985) reported that, regardless of the crop grown, yields decreased with the increasing depth of soil removed. The application of N, or N and P, tended to overcome yield decreases during the years fertilizer was applied. Although extractable P initially was very low in the newly exposed soil, there was a gradual increase during the first 8 yr after soil removal. Olson (1977) studied the effect of topsoil removal on corn (*Zea mays* L.) production on a Beadle silty clay loam (fine, montmorillonitic, mesic Typic Argiustolls). Removing 0.3 m of topsoil decreased yields, but removing an additional 0.15 m did not further decrease yields. Removing a portion of the soil profile had little effect on grain yield when 0.15 m of topsoil was replaced. Sixteen years after topsoil removal, Olson (personal communication of Olson to Burnett, 1982) reported that the subsoil plots remained in poor physical condition, and corn grown on these plots continued to exhibit early nutrient deficiency symptoms; plants were smaller throughout the growing season, and yields were lower than in surrounding areas (Burnett et al., 1985).

The results of other land leveling experiments have been reported by Carlson et al. (1961), Reuss and Campbell (1961), Black (1968), Robertson and Gardner (1946), Gingrich and Oswalt (1965), Mickelson (1968), Haas and Willis (1968), and Hauser and Cox (1962). Generally, if subsoil horizons were markedly different from topsoil in chemical or physical characteristics, crop yields were reduced. If nutrient deficiencies were the only problem, yields could be increased comparable to those on topsoils; but if physical conditions were poor in the subsoil, it was very difficult to restore productivity. In these studies, time-induced changes in soil chemical and physical properties and productivity were not measured.

Eck et al. (1965) and Eck (1968, 1969) evaluated the effects of various degrees of soil removal (0-, 0.10-, 0.20-, 0.30-, and 0.41-m depths), and growth and yield responses to fertilization on Pullman clay loam soil (fine, mixed, thermic Torrertic Paleustolls), under both fully irrigated and limited water conditions. With full irrigation without fertilization, the removal of 0.10, 0.20, 0.30, and 0.41 m of soil reduced grain sorghum yields to 63, 50, 38, and 28%, respectively, of those on undisturbed soil. With fertilization, however, yields on plots cut up to 0.30 m were restored to levels obtained on fertilized, undisturbed soil. With limited water, yields were not completely restored by fertilizer. The lack of restoration was shown to be due to reduced water supplying capacity on the cut areas. The purpose of this study, a continuation of the last mentioned, was to evaluate the effects of 23 yr of exposure on the physical and chemical characteristics and the productivity of soil with various layers of topsoil removed.

METHODS AND MATERIALS

The study was conducted at the USDA Conservation and Production Research Laboratory, Bushland, TX. Pullman clay loam has a moderately permeable surface horizon (0–0.2 m) underlain by a dense, very slowly permeable montmorillonitic clay horizon (Bt1) extending from the 0.2- through the 0.5- to 0.6-m depth. Below this depth, the soil is somewhat more permeable. The depth to the highly calcareous *caliche* layer ranges from 1.2 to 1.5 m. At −0.033 and −1.5 MPa matric potentials, the soil contains approximately 0.43 and 0.27 m of water, respectively, in the top 1.2 m of the profile. Chemical and physical properties and a profile description of the soil have been reported previously (Unger and Pringle, 1981; Eck, 1968; Eck et al., 1965; Mathers et al., 1963). The site had been dryland farmed before being seeded to permanent pasture in 1950, and remained in pasture until this experiment was initiated in 1960.

Five depths of soil removal (cut) were studied with six fertilizer treatments. Depths of soil removal were 0, 0.10, 0.20, 0.30, and 0.41 m. Depths of cut were obtained by bench leveling an area of uniform 1% slope. Each cut indicated is the amount of cut at the center of the plot; e.g., on the 0.41-m cut plots, topsoil removal was from 0.36 to 0.46 m. Fertilizer treatments were randomized within the main plots. Fertilizer treatments were a check, N_2, P_2, N_2P_1, N_1P_2, and N_2P_2. The N_1 and N_2 rates were 157 and 224 kg/ha (indigenous NO_3^-–N plus applied N) in years when the crop was fully irrigated (1960–1962) and 78 and 112 kg/ha when grain sorghum was grown under limited water (preplant irrigation only) (1963–1965). The P_1 and P_2 rates were applied to give 12.5 and 19 mg/kg of $NaHCO_3$-extractable P (Eck et al., 1965). All P was applied during the initial, fully irrigated phase of the study.

Main plots (bordered areas) were 10.1 by 45.7 m. Planted areas on main plots were 8.2 by 45.7 m; subplots were 4.1 by 15.2 m. Main plots were replicated three times. The design varied from a randomized-block split plot in that the main plots were arranged with successive degrees of cut lying in sequence. Since this arrangement does not allow valid statistical analysis of main plot treatments (Eck et al., 1965), separate error terms were calculated to test fertilizer effects in each strip.

The experimental site was prepared in 1960, and grain sorghum was grown in 1960 through 1965. In 1960 through 1962, the site was fully irrigated, and in 1963 through 1965, limited water was applied (preplant irrigation only). The results of both studies have been published (Eck et al., 1965; Eck, 1968, 1969). The site was fallowed in 1966 and 1967, planted to tall wheatgrass (*Agropyron elongatum*) in 1968, and left undisturbed until 1983 when this phase of the study was initiated.

Soil properties evaluated in 1983 were wet aggregate size, particle size distribution, organic matter (OM), total N, NO_3^-–N, and $NaHCO_3$-extractable P. Productivity was evaluated by growing grain sorghum. In 1983, the site was moldboard plowed in May and planted in June. In 1983 and 1984, plots were fully irrigated; and, in 1985, sorghum was grown under limited water. In 1983, no fertilizer was applied so that carryover from the previous studies could be evaluated. In 1984 and 1985, N rates were those specified above.

Before disturbance in 1983, soil samples were taken for physical and chemical analysis. The check and N_2P_2 plots were sampled on the five soil removal treatments. In addition, composite samples were taken from undisturbed soil outside the experimental area. The area sampled was not disturbed when the soil removal study was initiated in 1960, and still supported the grass vegetation present at that time. One composite sample (of eight locations) was taken from each end, and one was taken along one side of the site. These *reference samples* were used to represent soil conditions at the time of subsoil exposure in 1960. Chemical and physical properties of the reference soil (especially in the surface 0.05 m) may have changed during the 23-yr period; however, since comprehensive data were not collected in 1960, the reference data are the best available. Samples were taken by 0.05-m increments to 0.15 m on the removal treatments, and to 0.56 m on the reference area. Surface samples (0–0.05 m) from the soil removal treatments and all reference samples were analyzed for particle size distribution and wet aggregation. Chemical determinations were made on all soil samples. Chemical data reported are the averages of data for the 0- to 0.05-, 0.05- to 0.10-, and 0.10- to 0.15-m depth samples. Corresponding reference sample data are averages for the three sample depths that the exposed soils occupied in the original soil profile.

Particle size distribution was measured by the hydrometer method (Day, 1965), and wet aggregate stability was determined by the method outlined by Kemper and Chepil (1965). Organic matter was determined by a variation of the method of Walkley and Black (Jackson, 1958). Nitrate-N was extracted by 0.1 *M* KCl and determined with an autoanalyzer (Kamphake et al., 1967). Total N was determined by the Kjeldahl method, and $NaHCO_3$-extractable P was determined by the method of Olsen et al. (1954).

Separate analyses of variance were calculated for each depth of soil removal. The reference samples were considered a treatment; thus, there were three treatments (unfertilized, fertilized, and reference) and three replications. When significant values were obtained, mean separation was by Duncan's multiple range test.

RESULTS

Changes in Soil Properties

Organic Matter

Where no topsoil was removed, the soil OM content was lower than that in the corresponding reference sample, indicating a trend toward decreased OM with both the unfertilized and fertilized treatments (Fig. 1A) over the 23-yr exposure period. Though not statistically significant at the 5% probability level, the decrease appears to be real. A decrease probably occurred during the period when the site was cropped, and any increase during the period when grass was grown was not sufficient to compensate for the earlier losses. Where 0.10 m of topsoil was removed, the OM level on the formerly cropped area was similar to that at a like depth in the reference soil. When 0.20 m of topsoil was removed, there was a definite trend toward higher OM on the exposed subsoil; and with 0.30 or 0.41 m of soil removal, OM levels in the exposed subsoil were significantly higher than those in the reference soil. The application of fertilizer during the cropping period did not have a consistent effect on OM levels in the exposed subsoil.

Total Nitrogen

Total N concentrations in the soil followed trends similar to those of OM (Fig. 1B). Nitrogen levels were lower in the cropped soil than in the reference soil where topsoil had not been removed. With 0.10 m of topsoil removal, there was a slight trend toward lower N on the exposed subsoil; but with 0.20 m of topsoil removal, the trend was reversed. Exposed subsoil with 0.30 or 0.41 m of topsoil removal contained higher N concentrations than the reference soil. As with OM, the application of fertilizer during the cropping period did not have a consistent effect on N levels in the exposed subsoil.

Nitrate–Nitrogen

Nitrate–N data are not presented in detail. They were very low on all treatments on all depths of topsoil removal. Levels were similar on the unfertilized and fertilized treatments. Average values for the two treatments decreased from 1.25 mg/kg on the uncut soil to 0.53 mg/kg on the 0.41-m cut soil. On the reference soil, values were similar for all depths of removal. The average value for all depths was 0.18 mg/kg. Although the reference soil was significantly lower in NO_3^-–N than the exposed soil at the 0-, 0.10-, 0.20-, and 0.30-m removal depths, actual differences were small and may have been attributable to differences in vegetation growing on the soil at the time of sampling.

Sodium Bicarbonate-Extractable Phosphorus

The unfertilized exposed subsoil layers and their corresponding reference samples contained similar amounts of extractable P (Fig. 1C). Thus, exposure did not affect extractable P levels. The higher extractable P levels on the fertilized plots resulted from P fertilizer applied during the first phase of the study.

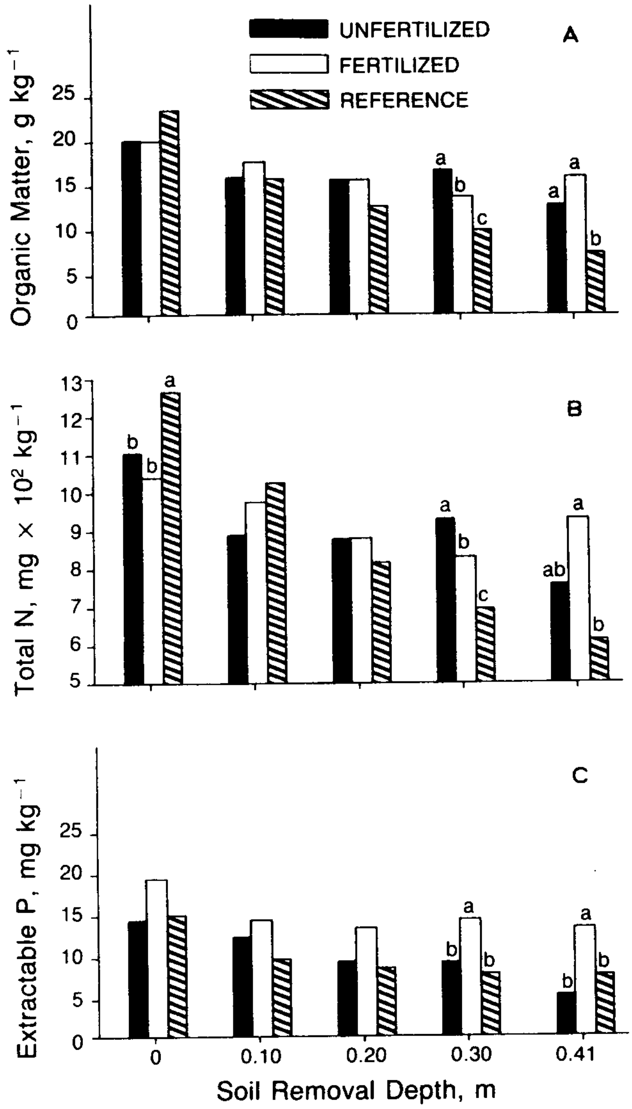

Fig. 1. Chemical characteristics of exposed and reference subsoil, 23 yr after exposure. (A) Organic matter, (B) Total N, (C) $NaHCO_3$-extractable P. Values at the same soil depth not accompanied by letters or accompanied by the same letter are not significantly different at the 0.05 level.

Particle Size Distribution

There were only minor differences in particle size distribution among the three treatments, and they could not be attributed to exposure (data not shown). In a soil with stable particles such as this one, changes in particle size distribution would be by sorting, either by water or wind action. As the area was leveled when the study was started, there was little runoff to cause removal of fine particles by water, and vegetative cover prevented wind action. Thus, the measurement of particle size distribution was more a measure of site homogeneity than the effects of exposure. Particle size distributions in the reference samples were similar to those in corresponding layers of the experimental site, indicating that the reference samples were representative of the experimental site.

Wet Aggregate Stability

The major difference among treatments in the size distribution of soil aggregates wetted under vacuum and sieved under water occurred where there was no soil removal (Table 1). The larger proportion of large aggregates (4.0–12.7 mm) and the smaller proportion of small aggregates (0.25–1.0 mm) from the reference area probably resulted from the vegetation that existed at the time of sampling rather than from changes with time. The sod cover was much more dense on the reference area, and the surface layer contained more OM, providing more material for cementing primary particles together. Also, aggregation in the reference soil probably increased during the 23-yr-longer period that it was left undisturbed, accentuating differences between the reference and treatment soils.

Table 1. Size distribution of water-stable aggregates in exposed and reference subsoil 23 yr after exposure.†

Soil removal depth (m) and treatment	Size range, mm <0.25	0.25–1.0	1.0–2.0	2.0–4.0	4.0–12.7	MWD‡
	%					
0						
Unfertilized	34.2	39.9a*	11.4	8.0	6.5b	1.25b
Fertilized	33.9	41.5a	11.2	8.8	4.6b	1.12b
Reference	25.1	24.6b	11.4	12.2	26.7a	2.95a
0.10						
Unfertilized	36.7	38.6	9.9	7.1	7.7	1.29
Fertilized	28.9	43.9	12.6	8.3	6.3	1.28
Reference	27.2	34.6	13.5	10.9	13.8	1.93
0.20						
Unfertilized	37.4	44.0	9.3	6.1	3.2b	0.91
Fertilized	42.3	40.9	6.7	4.8	5.3b	0.99
Reference	33.2	35.6	11.8	8.4	11.0a	1.51
0.30						
Unfertilized	49.9	34.5	6.9b	5.6	3.1	0.80
Fertilized	31.5	43.7	10.9a	7.6	6.3	1.22
Reference	38.3	33.9	10.3a	7.3	10.2	1.48
0.41						
Unfertilized	43.0	34.4ab	10.2	7.4	5.0b	1.07
Fertilized	36.5	39.8a	12.5	6.0	5.2b	1.11
Reference	41.2	31.8b	9.0	6.5	11.5a	1.47

* Values in columns not followed by letters or followed by the same letter are not significantly different at the 0.05 level.

† On exposed soils, values are for the surface 50 mm; on reference soils, values are for the corresponding 100-mm depth (to compensate for mixing on exposed soils).

‡ Mean weight diameter.

There were trends toward increased percentage of large water-stable aggregates (4.0–12.7 mm) in the unexposed soil compared to the exposed subsoil at all depths, and differences were statistically significant at 0.20 and 0.41 m of soil removal. However, these and other differences in aggregate stability were small in comparison to those where no topsoil was removed.

There were trends toward increased mean weight diameter (MWD) on the reference soil at all depths of removal, but the only significant difference between the reference and treated soils was on the area of zero soil removal.

Effects on Soil Productivity

In 1983, there was little time for decomposition of the buried organic material and mineralization of soil N before the crop was planted. The plants on all degrees of soil removal exhibited N deficiency, with the degree of deficiency increasing with the depth of removal. Nitrogen deficiency delayed maturity; thus, when a killing frost occurred on 20 September (about 40 days before the average date), immaturity increased with the depth of soil removal. For that reason, biomass yields may be more representative of treatments than grain yields. Yields were measured on the unfertilized, N_2, P_2, and N_2P_2 treatments only. Because there were no significant differences in grain or biomass yields due to residual fertilizer with any of the soil removal treatments, the data are not presented in detail. Biomass yields (averaged over five depths of soil removal) on the unfertilized, N_2P_0, N_0P_2, and N_2P_2 treatments were 3.86, 4.06, 3.68, and 4.39 Mg/ha, respectively. Grain yields on the respective treatments were 0.65, 0.99, 0.73, and 1.05 Mg/ha. Differences in biomass and grain yields resulting from soil removal were more marked than those from residual N treatments. Biomass yields (averaged over the four fertilizer treatments) on the 0-, 0.10-, 0.20-, 0.30-, and 0.41-

Table 2. Effects of depth of topsoil removal and fertilizer treatments on sorghum grain yields after 23 yr of subsoil exposure, fully irrigated (1984), and pre-irrigated only (1985).†

Depth of soil removal	Check	P_2	N_1P_2	N_2	N_2P_1	N_2P_2
m	Mg/ha					
			1984			
0	4.95b*	5.89b	7.28a	6.93a	7.06a	7.49a
0.10	4.49b	4.66b	6.39a	6.53a	7.31a	6.81a
0.20	3.05b	3.46b	5.96a	5.85a	6.16a	6.42a
0.30	3.03b	3.26b	6.27a	6.06a	6.26a	6.48a
0.41	2.63c	3.28c	5.65ab	4.94b	5.73ab	6.19a
			1985			
0	3.54a	3.53a	3.52a	3.21a	3.23a	3.35a
0.10	3.30a	3.19a	3.33a	2.99a	3.34a	3.51a
0.20	2.86a	2.82a	3.30a	3.25a	3.24a	3.35a
0.30	2.55c	2.71bc	3.41a	3.37ab	3.31ab	3.12a
0.41	2.23a	2.48a	3.12a	2.96a	2.98a	2.89a

* Means in the same row followed by the same small letter are not significantly different at the 0.05 level.

† Fertilizer treatments: 1960 to 1962 and 1984, N_1–N applied to give 157 kg/ha N (soil NO_3^-–N plus fertilizer N), N_2–N applied to give 224 kg/ha N (soil NO_3^-–N plus fertilizer N), P_1–P applied to give 12.5 mg/kg $NaHCO_3$-extractable P, P_2–P applied to give 19 mg/kg $NaHCO_3$-extractable P. All P applied in 1960 to 1962. Fertilizer treatments: 1963 to 1965 and 1985, N_1–N applied to give 78 kg/ha (soil NO_3^-–N plus fertilizer N), N_2–N applied to give 112 kg/ha (soil N plus fertilizer N).

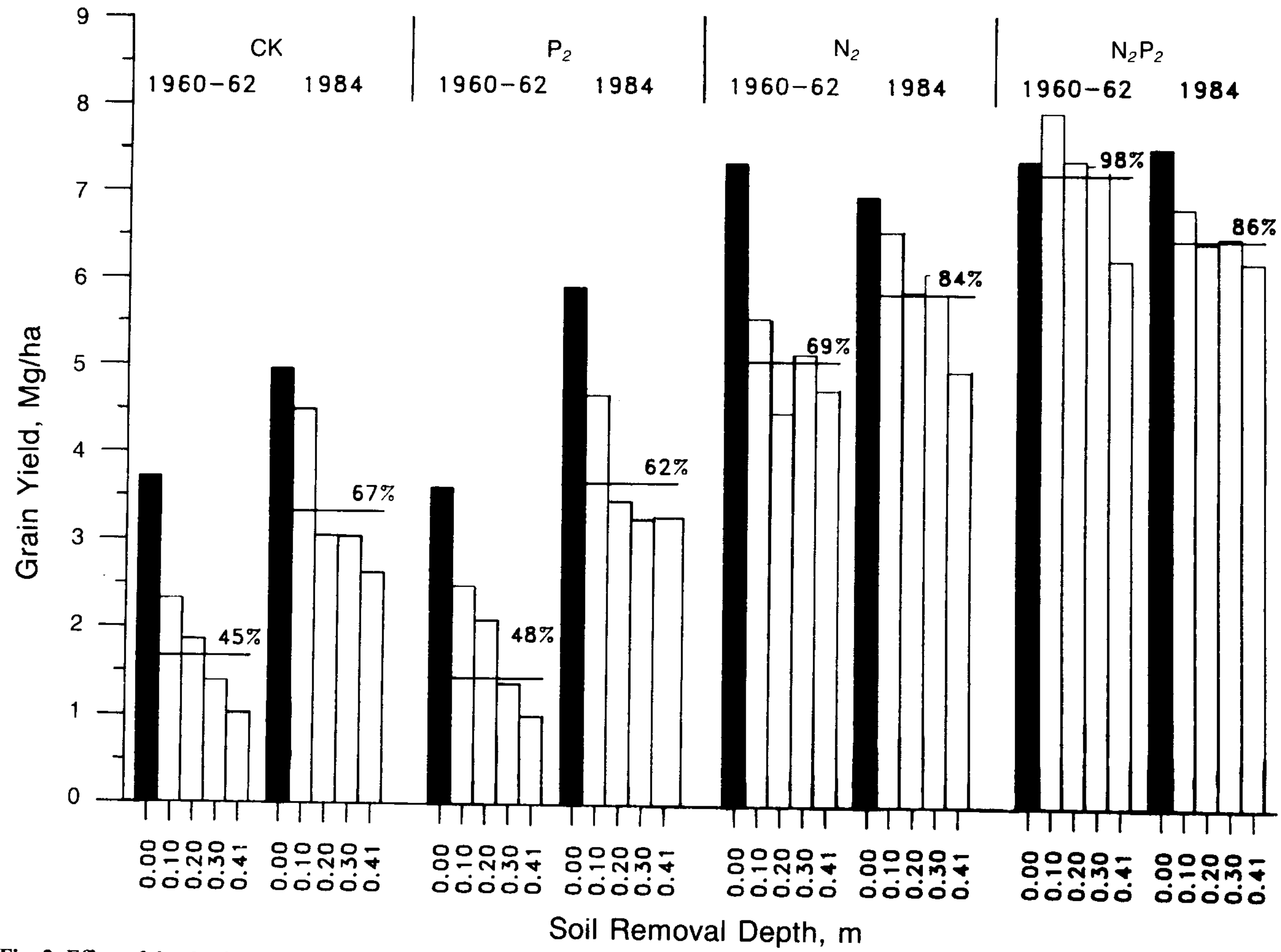

Fig. 2. Effect of depth of topsoil removal and fertilizer treatments on yields of fully irrigated grain sorghum at topsoil removal and after 23 yr of subsoil exposure. N_2–N applied to give 224 kg/ha N (soil NO_3^-–N plus fertilizer N). P_2–P applied to give 19 mg/kg $NaHCO_3$-extractable P. All P applied in 1960 to 1962.

m depths of cut were 5.80, 4.87, 3.22, 3.04, and 3.05 Mg/ha, respectively. Grain yields on the respective depths of cut were 1.77, 0.98, 0.61, 0.53, and 0.38 Mg/ha. The trends toward higher yields on previous N treatment plots and the decrease in yields with depth of soil removal appear to be due to differences in N mineralization since all plots were practically devoid of NO_3^-–N when sampled before plowing in May.

In 1984, on all except the 0.41-m cut, all treatments receiving N resulted in statistically equivalent grain yields, but on the 0.41-m cut, a significant response to P was also obtained (Table 2). These results indicate that P was not limiting in exposed subsoil where as much as 0.30 m of topsoil had been removed. However, at each removal depth, there was a trend toward increased yield when P was applied (compare treatments N_2 and N_2P_2), indicating at least an incipient P deficiency at all depths of soil removal. Nitrogen was required for maximum yields at all depths of soil removal. The N_1 and N_2 rates gave statistically equivalent yields on all depths of soil removal, but there were trends toward higher yields with the higher N rate, especially on the deeper cuts.

In 1985, under limited water, there were no significant differences in yield due to fertilizer treatments except with the 0.30-m depth of soil removal where there was a response to N. There were, however, trends toward higher yields with the first increment of applied N, especially where 0.20 m or more of soil had been removed (Table 2).

Yields obtained in 1984 and 1985 are compared with those obtained in the earlier studies in Fig. 2 and Fig. 3. The yield resulting from the fully watered, zero soil removal, unfertilized treatment in 1984 was 33% higher than the yield on the same treatment in 1960 to 1962. With the unfertilized treatment, yield decreases due to soil removal averaged 55% in 1960 to 1962 and 33% in 1984. The yield with the P_2 treatment in 1984 was 64% more than the yield with that treatment in 1960 to 1962. Average yield decreases due to soil removal with the P_2 treatment were 52% in 1960 to 1962 and 38% in 1984. Yields with the zero soil removal, N_2, and N_2P_2 treatments in 1984 were similar to those obtained in 1960 to 1962. Average yield decreases from soil removal with the N_2 treatment were 31 and 16% in 1960 to 1962 and 1984, respectively. Decreases from soil removal with the N_2P_2 treatment were 2% in 1960 to 1962 and 14% in 1984. These data show definite increases in productivity of the exposed subsoils between 1960 to 1962 and 1984.

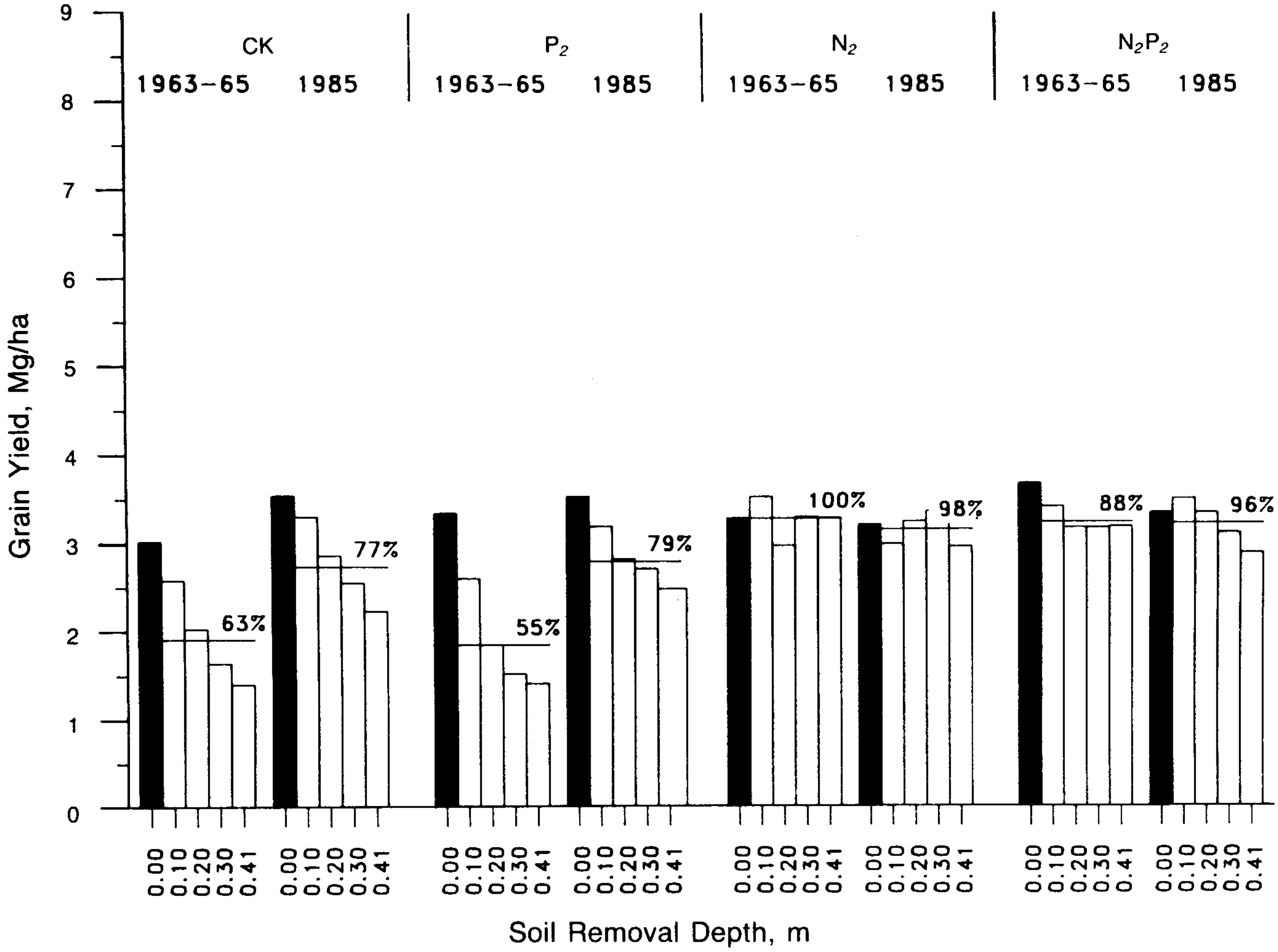

Fig. 3. Effects of depth of topsoil removal and fertilizer treatments on yields of grain sorghum grown under limited water (pre-irrigated only) at topsoil removal and after 23 yr of subsoil exposure. N_2-N applied to give 112 kg/ha N (soil NO_3^--N plus fertilizer N). P_2-P applied to give 19 mg/kg $NaHCO_3$-extractable P. All P applied in 1960 to 1962.

With limited water, yield potentials were lower; thus, increases in productivity were less marked but still substantial (Fig. 3). The yield with the 0 soil removal, unfertilized treatment in 1985 was 17% higher than the yield during 1963 to 1965. With the unfertilized treatment, yield decreases due to soil removal averaged 37% in 1963 to 1965 and 23% in 1985. The yield with the P_2 treatment in 1985 was only 6% more than the yield with that treatment in 1963 to 1965. Average yield decreases due to soil removal with the P_2 treatment were 45% in 1963 to 1965 and 21% in 1985. Yields with the 0 soil removal, N_2, and N_2P_2 treatments in 1985 were similar to those obtained in 1963 to 1965. Soil removal did not decrease yields on the N_2 treatment in 1963 to 1965, and, in 1985, the average decrease was 2%. The average yield decreases due to soil removal on the N_2P_2 treatment were 12% in 1963 to 1965 and 4% in 1985.

DISCUSSION

The OM content of an arable soil tends to equilibrate depending on the crop rotation practiced for a given soil under given climatic conditions (Russell, 1961). In this study, the trends toward decreasing OM and N in the surface soil layer, which was initially comparatively high in those constituents, and the increases in the exposed subsurface layers, which were initially low in OM, exhibit moves toward equilibria being established under existing vegetation and climatic conditions. The OM and N levels in the uncut soil may have decreased during the initial period of cropping, then remained stable or increased during the period that grass was grown, or may have declined constantly in becoming adjusted to cultivation and then to tall wheatgrass vegetation. Organic matter and N levels in the exposed subsoil probably increased during both cultivation and wheatgrass vegetation. Since the fertilizer N applied during the period of cultivation did not affect the OM, total N, or the NO_3^--N content of the soil, it is concluded that most of the fertilizer N was removed by plants, denitrified, or leached from the soil during the period of cultivation.

The very low NO_3^--N levels indicate that no labile pool of N was present in either the exposed or reference soil. This is usual in soils under grass cover in this area.

Sodium bicarbonate extractable P levels in the exposed subsoil did not change significantly during the 23 yr of exposure. Greb and Smika (1985) attributed increases in extractable P in Weld subsoil to mineralization of organic P and biological mobilization of inorganic P forms. Apparently, these processes were not active enough to produce significant changes in $NaHCO_3$-extractable P in Pullman subsoil. However, the productivity data show that P supplying capacity increased during the period of exposure.

Plots that had received P fertilizer were higher in $NaHCO_3$-extractable P than those that had not. Laboratory equilibration studies at the initiation of the experiment showed that 20% of applied P remained in the $NaHCO_3$-extractable form (Eck et al., 1965); thus, the amounts of P applied to raise extractable P to the specified level were sufficient to maintain an increased extractable P level throughout the 23-yr period.

There were few changes in physical properties of subsoil resulting from exposure. Particle size distribution remained essentially unchanged. The proportion of large water-stable aggregates decreased, and that of small aggregates increased, probably due to cultivation and to the change in types of grass cover. The fertilizer treatment did not have a consistent effect on the physical properties measured.

Productivity of the subsoil layers increased during the 23-yr period of exposure. Increases resulted from the increased supplying capacity of both N and P. The 94% higher yield on the P_2 treatment plots in 1984 compared to that in 1960 to 1962 illustrates the increased N supplying capacity, and the 10% increase on the N_2 treatment illustrates a more moderate increase in P supplying capacity. The fact that yields were higher with the N_2P_2 treatment than with the N_2 treatment on all but the undisturbed layer in 1960 to 1962, and that yields with the N_2 treatment were statistically equivalent to those with the N_2P_2 treatment on all except the 0.41-m removal treatment in 1984, is a further manifestation of increased P supplying capacity.

REFERENCES

Black, A.L. 1968. Conservation bench terraces in Montana. Trans. ASAE 11:393–395.

———, and B.W. Greb. 1968. Soil reflectance, temperature, and fallow water storage on exposed subsoils of a brown soil. Soil Sci. Soc. Am. Proc. 32:105–109.

Burnett, E., B.A. Stewart, and A.L. Black. 1985. Regional effects of soil erosion on crop productivity—Great Plains. p. 285–304. *In* R.F. Follet and B.A. Stewart (ed.) Soil erosion and crop productivity. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI.

Carlson, C.W., D.L. Grunes, J. Alessi, and G.A. Reichman. 1961. Corn growth on Gardena surface and subsoil as affected by applications of fertilizer and manure. Soil Sci. Soc. Am. Proc. 25:44–47.

Day, P.R. 1965. Particle fractionation and particle size analysis. *In* C.A. Black et al. (ed.) Methods of soil analysis. Part I. Agronomy 9:545–567.

Eck, H.V. 1968. Effect of topsoil removal on nitrogen supplying ability of Pullman silty clay loam. Soil Sci. Soc. Am. Proc. 32:686–691.

———. 1969. Restoring productivity on Pullman silty clay loam subsoil under limited moisture. Soil Sci. Soc. Am. Proc. 33:578–581.

———, V.L. Hauser, and R.H. Ford. 1965. Fertilizer needs for restoring productivity on Pullman silty clay loam after various degrees of soil removal. Soil Sci. Soc. Am. Proc. 29:209–213.

Gingrich, J.R., and E.S. Oswalt. 1965. Soil management practices for cotton production on leveled irrigated land. Oklahoma Agric. Exp. Stn. Bull. B-636.

Greb, B.W., and D.W. Smika. 1985. Topsoil removal effects on soil chemical and physical properties. p. 316–327. *In* S.A. El-Swaify et al. (ed.) Soil erosion and conservation. Soil Conservation Society of America, Ankeny, IA.

Haas, H.J., and W.O. Willis. 1968. Conservation bench terraces in North Dakota. Trans. ASAE 11:396–398.

Hauser, V.L., and M.B. Cox. 1962. Evaluation of Zingg conservation bench terraces. Agric. Eng. 43:462–464, 467.

Jackson, M.L. 1958. Organic matter determination for soils. p. 205–226. *In* Soil chemical analysis. Prentice-Hall, Englewood Cliffs, NJ.

Kamphake, L.J., S.A. Hannah, and J.M. Cohen. 1967. Automated analysis for nitrate by hydrazine reduction. Water Res. 1:205–216.

Kemper, W.D., and W.S. Chepil. 1965. Size distribution of aggregates. *In* C.A. Black et al. (ed.) Methods of soil analysis. Part I. Agronomy 9:499–510.

Mathers, A.C., H.R. Gardner, F.B. Lotspeich, H.M. Taylor, G.R. Laase, and R.E. Daniell. 1963. Some morphological, physical, chemical, and mineralogical properties of seven Southern Great Plains soils. USDA-ARS 41-85. U.S. Government Printing Office, Washington, DC.

Mickelson, R.H. 1968. Conservation bench terraces in eastern Colorado. Trans. ASAE 11:389–392.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 939. U.S. Government Printing Office, Washington, DC.

Olson, T.C. 1977. Restoring the productivity of glacial till soil after topsoil removal. J. Soil Water Conserv. 32:130–132.

Reuss, J.O., and R.E. Campbell. 1961. Restoring productivity to leveled land. Soil Sci. Soc. Am. Proc. 25:302–304.

Robertson, D.W., and R. Gardner. 1946. Restoring fertility to land where leveling operations have removed all the topsoil and left raw subsoil exposed. p. 33–35. *In* Proc. 4th Genl. Mtg. Am. Soc. of Sugar Beet Technol., Denver, CO. 12–14 Feb. 1946. American Society of Sugar Beet Technologists, Fort Collins, CO.

Russell, E.W. 1961. The composition of the soil organic matter. p. 264–295. *In* Soil conditions and plant growth. 9th ed. John Wiley & Sons, Inc. New York.

Smith, R.M., R.C. Henderson, E.D. Cook, J.E. Adams, and D.O. Thompson. 1967. Renewals of desurfaced Austin clay. Soil Sci. 103:126–130.

Unger, P.W., and F.B. Pringle. 1981. Pullman soil: Distribution, importance, variability, and management. Texas Agric. Exp. Stn. Bull. 1372.